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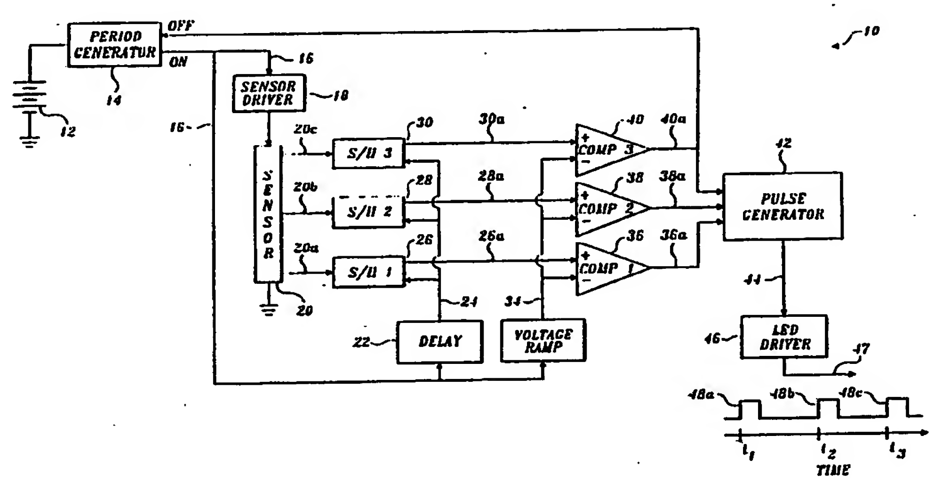

(57) Abstract

A method and apparatus for transmitting information indicative of an output signal of a sensor (20) to a remote location. The method comprises the steps of transmitting a first pulse (48a), a second pulse (48b) and a third pulse (48c) to a receiving circuit (50) at times that are ratiometrically related to the output signal of the sensor. The receiving circuit receives the first, second and third pulses and computes a number indicative of the value of the output signal of the sensor as a function of the times at which the three pulses are received. In the preferred embodiment, the sensor is powered by a battery (12) and transmits the first, second, and third pulses to the receiver circuit as light pulses conveyed on a fiber-optic cable.

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METHOD AND APPARATUS FOR TRANSMITTING INFORMATION FROM A SENSOR USING TIME PULSE CODE MODULATION

Field of the Invention

The present invention relates to electronic sensors in general, and in particular to a method and apparatus for transmitting information to a remote location.

Background of the Invention

Automated control systems that use a central computer to control the operation of a machine or process often collect data indicative of the physical parameters of the system from a plurality of remotely located sensors. The sensor data are used by the central computer when generating a series of signals that control the operation of the machine or process. Such remote sensors are critically important in automated aircraft control systems where they are used for such diverse functions as monitoring the position of the aircraft's control surfaces and landing gear, monitoring the amount of fuel on board, and the speed and altitude of the aircraft. Generally, such remote sensors or transducers are placed in close proximity with the physical parameter to be monitored and transmit an output signal to the central computer via a common data bus or dedicated signal path, such as a wire.

In a large aircraft, the amount of wire needed to connect all the remote sensors to a central flight control computers can be considerable. Each sensor usually requires connection to a power bus via a power lead and a ground lead and also requires a separate lead that carries the output signal of the sensor to the central computer. In such a control system, the required wire can add significantly to the overall weight of the system. Minimizing the tare weight of an aircraft is usually an important design goal.

With the advent of fiber optic technology, it has become possible to achieve a significant reduction in the weight of this type of system by replacing the wires that connect a remotely located sensor to a central computer with a fiber optic cable. Not only are fiber optic cables much lighter than copper wires, they are also immune to electromagnetic coupling, have an increased bandwidth, and can be easily routed throughout an aircraft. However, even if a fiber optic cable is used to connect the remotely located sensor to the central computer, power must be still be supplied to drive the sensor. If standard power busses are used to provide power to each sensor and a fiber optic cable is used to transmit the output signal of the sensor, the overall weight of the system will not be significantly decreased, and full immunity to electromagnetic coupling will not be achieved. Alternatively, it may be possible to power the sensor by transmitting light down the fiber optic cable to the sensor and converting the light to electric power or by providing power from a long life battery, such as a lithium cell. Lithium cells have a characteristic shelf life of many years and allow a sensor that is coupled to a central computer by a fiber optic cable to be completely isolated from the other electrical systems of the aircraft.

Only limited power can be supplied to a remote sensor by either a long life lithium cell or a photocell using transmitted light that is converted to electrical power. Therefore, what is needed is a remote sensing system that draws minimum electrical power and allows a sensor to be electrically isolated from the remainder of the automated system. It is also desirable to provide a remote sensor transmitting circuit that uses a single fiber optic cable to connect each sensor to a common receiving circuit. Finally, it is desirable to provide a remote sensing circuit, which allows a high resolution output signal to be transmitted from the remote sensor.

Summary of the Invention

The present invention relates to a method and apparatus for transmitting information indicative of an output signal of a sensor to a remote location. The output signal of the sensor lies between a minimum sensor value and a maximum sensor value. The method comprises transmitting at least a first signal, a second signal, and a third signal to the remote location. The time at which the second signal is transmitted compared to the time at which the first and third signals are transmitted is ratiometrically related to the value of the output signal of the sensor. In the preferred embodiment, the first signal comprises a first pulse transmitted at a time t_1; the second signal comprises a second pulse transmitted at a time t_2; and

the third signal comprises a third pulse transmitted at a time t_3. The time t_2 is selected such that the ratio of the time $(t_2 - t_1)$ to the time $(t_3 - t_1)$ is indicative of the output value of the sensor. Means are disclosed for transmitting the first, second, and third signals to the remote transmitter over a fiber-optic cable. A remote receiver receives the transmitted pulses and computes these ratios to obtain a value indicative of the output signal of the sensor and, thus, of a parameter measured by the sensor.

Brief Description of the Drawings

FIGURE 1 is a block diagram of a sensor transmitter according to the present invention;

FIGURE 2 is a schematic diagram showing how a sensor is connected to a sensor transmitter according to the present invention;

FIGURE 3 is a timing diagram illustrating a pulse time modulation technique according to the present invention;

FIGURE 4 is a block diagram of a sensor receiver according to the present invention;

FIGURE 5 is a schematic diagram of a math block included in FIGURE 3.

Detailed Description of the Preferred Embodiment

FIGURE 1 is a block diagram of a sensor transmitter according to the present invention, shown generally at 10. A battery 12 is connected to a period generator 14 that provides the sensor transmitter 10 with a series of low duty cycle power pulses. In the preferred embodiment, electrical current is only provided to the transmitter 10 when the period generator 14 is providing a power pulse in order to extend the life of the battery 12. When the period generator is pulsing "on," a power pulse is provided on a lead 16 to each circuit within transmitter 10, including a sensor driver circuit 18, a delay circuit 22, and a voltage ramp generating circuit 32. Upon receipt of the power pulse, sensor driver circuit 18 energizes a sensor 20. Sensor 20 can comprise a variety of electrical transducers, such as a linear variable differential transformer (LVDT), temperature sensing transducer, pressure sensing transducer, velocity sensing transducer, etc. Coupled to sensor 20 are three sample and hold circuits 26, 28, and 30. Sample and hold circuit 26 is connected to sensor 20 by a lead 20a. Sample and hold circuit 28 is connected to sensor 20 by a lead 20b, and sample and hold circuit 30 is connected to sensor 20 by a lead 20c. Preferably, the sensor 20 comprises an electrical bridge circuit that provides two signals that remain relatively fixed in magnitude on

leads 20a and 20c and a varying signal that is indicative of the parameter being sensed on lead 20b.

After receiving a power pulse on lead 16, delay circuit 22 waits a predetermined period of time (typically 10 microseconds) to allow any transient currents that may be flowing in sensor 20 to settle down before placing a hold signal on a lead 24, which is coupled to each of the sample and hold circuits 26, 28, and 30. The hold signal causes the sample and hold circuits 26, 28, and 30 to lock on to the signal values on leads 20a, 20b, and 20c, respectively.

Upon receipt of the power pulse on lead 16, the voltage ramp generator 32 begins generating a linearly varying voltage signal that extends from a level below the voltage on lead 20a to a value greater than the voltage on lead 20c. This linearly varying voltage signal is applied to the inverting inputs of three comparator circuits 36, 38, and 40 on a lead 34. Connected to the non-inverting inputs of comparators 36, 38, and 40 are the output voltages of the sample and hold circuits 26, 28, and 30, respectively. The output of sample and hold circuit 26 is connected to the non-inverting input of comparator 36 by a lead 26a. The output of sample and hold circuit 28 is connected to the non-inverting input of comparator 38 by a lead 28a, and the output of sample and hold circuit 30 is connected to the non-inverting input of comparator 40 by a lead 30a. When the value of the linearly varying voltage signal on lead 34 exceeds the output signals of the sample and hold circuits 26, 28, and 30, each of the comparators 36, 38, and 40 applies an output signal pulse to a pulse generator circuit 42.

When the pulse generator circuit 42 receives the pulses from comparators 36, 38 and 40, it generates a short pulse, approximately 100 nanoseconds long, which is transmitted to a light emitting diode (LED) driver 46 on a lead 44. LED driver 46 is coupled to a fiber optic cable 47, which carries a light pulse to a receiving circuit (shown in FIGURE 4). When comparator 36 applies an output signal pulse to the pulse generator circuit 42, a pulse 48a is transmitted on the fiber optic cable at a time t_1. Similarly, as comparators 38 and 40 apply output signal pulses to the pulse generator circuit 42, a pair of light pulses 48b and 48c are transmitted on the fiber optic cable at times t_2 and t_3, respectively. The output signal pulse that is applied to pulse generator circuit 42 by comparator 40 when the linearly varying voltage signal exceeds the output signal of sample and hold circuit 30 is also fed back to the period generator 14, causing the power pulse to turn "off" and halting the drain of current from battery 12.

By using a linearly varying voltage signal on lead 34, the time at which the light pulses 48a, 48b, and 48c are transmitted is proportional to the magnitude of the signals sampled by the sample and hold circuits 26, 28, and 30. If the output signal of sensor 20 had a lower limit of three volts, an upper limit of nine volts, and the signal on lead 20b was sampled at six volts, (i.e. the output signal of the sensor was halfway between the minimum and maximum values) the time at which the second light pulse 48b is transmitted would be midway between the times at which pulses 48a and 48c are transmitted.

FIGURE 2 shows the preferred way of connecting a sensor 20 to the transmitting circuit. The sensor 20, which is shown for illustrative purposes as a variable inductor L_1 and a fixed inductor L_2, is connected in a bridge circuit that includes resistors R_{S1}, R_{S2} and R_{S3}. The values of these bridge resistors are chosen so that the voltages on leads 20a and 20c are always outside the expected range of output signal on lead 20b. Using the above example, if the sensor 20 has an output signal that varies between 3 and 9 volts, then the voltage on lead 20a is set to be less than 3 volts while the voltage on lead 20c is set to be always greater than 9 volts. In the preferred embodiment, the voltages on leads 20a and 20c are calibrated such that the expected range of output signal voltages on lead 20b is 80% of the difference between the voltages on lead 20c and 20a. In the present example, the voltage on lead 20a is set at 2.25 volts while the voltage on lead 20c is set at 9.75 volts (9 - 3 is 80% of 9.75 - 2.25). The voltages on leads 20a and 20b can be set at any percentage of the expected range of the output signal of sensor 20, so long as the receiver circuit is designed to accommodate the selected percentage parameter when interpreting the ratio of the times at which the light pulses are sent.

FIGURE 3 is a timing diagram showing a pulse time modulation technique according to the present invention. A voltage V_1 is representative of the fixed voltage on lead 20a of the sensor 20 (shown in FIGURE 1), a voltage V_2 is representative of the output signal of the sensor, and a voltage V_3 is representative of the fixed voltage on lead 20c. A linearly varying voltage signal V_C begins at a level lower than the magnitude of voltage V_1 and increases until it exceeds the magnitude of voltage V_3. In the preferred embodiment, the voltage V_C is generated by charging a capacitor with a constant current. However, those skilled in the art realize that other methods of generating a linearly varying signal could be substituted. As the voltage V_C exceeds the voltage V_1, the first pulse 48a is transmitted at a time t_1. When the value of voltage V_C exceeds the voltage V_2,

the second pulse 48b is transmitted at a time t_2. Finally, when voltage V_C exceeds voltage V_3, the third pulse 48c is transmitted at a time t_3.

The magnitude of voltage V_2 (i.e. the output signal of the sensor) in FIGURE 3 is shown, for illustrative purposes, as being equal to 60% of the sensor's maximum output signal value. The time at which the second pulse 48b is transmitted is 58% of the time between when the first pulse transmitted at time t_1 and when a third pulse transmitted at time t_3. Because of the levels at which the voltages V_1 and V_3 are set, if the output signal of the sensor is at a minimum, the second pulse 48b is transmitted at time t_2 that occurs when 10% of the time interval between the transmission of the first and third pulses has elapsed. Similarly if the output signal of the sensor is a maximum, the second pulse is transmitted at a time t_2 occurring when 90% of the time interval between the transmission of the first and third pulses has elapsed. Thus, an output signal having a value of 60% of the maximum sensor output is transmitted at a time t_2 occurring when 58% of the time interval between the transmission of the first and third pulse has elapsed and not at 60% of the time interval. However, the time of the second pulse in relation to the times of the first and third pulses can be adjusted by changing the values of the fixed voltages V_1 and V_3. As will be described below, a receiver circuit (shown in FIGURE 4) decodes the time at which the second pulse was transmitted in respect to the times of the first and the third pulses to determine a value for the sensor output signal.

It will thus be understood that the absolute time at which the second pulse is transmitted is not important; instead, the ratio of the time after the first pulse at which the second pulse is transmitted and the time interval between the first and third pulses is indicative of the output signal of the sensor. Therefore, it is not necessary for the time base of the present system to remain accurate. The transmitter circuit 10 shown in FIGURE 1 can be manufactured in a hermetically sealed canister and placed at a remote location in an aircraft so that it need not be compensated for variations in temperature or humidity that might otherwise affect the accuracy of the sensor system. Variations in the slope of the linearly varying signal V_C, due to thermal conditions, do not effect the accuracy of the sensor transmitter, because the ratio of time at which the pulses are transmitted remains ratiometrically constant. Although the signal V_C is shown with a positive slope beginning at a level less than the magnitude of the voltage V_1 and extending to a level greater than the magnitude of voltage V_3, those skilled in the art will realize that a linearly varying signal having a downward slope, extending from a level

above V_3 to a level below V_1 could be substituted without affecting the accuracy of the present invention.

FIGURE 4 is a block diagram of a receiver circuit shown generally at 50. The receiver circuit 50 receives the light pulses transmitted from the sensor transmitter 10 (shown in FIGURE 1) and produces a digital signal that corresponds to the output signal of the remote sensor. In the preferred embodiment, the receiver circuit is multiplexed to receive pulses from a plurality of remotely-located sensor circuits. A detector/pre-amp comparator 52 receives the light pulses transmitted from the sensor on the fiber optic cable 47 and compares them to a predetermined noise threshold. If the signals received exceed the threshold, comparator 52 provides a pulsed output signal on a lead 54 that corresponds to the light pulses received. The signals on lead 54 are coupled to a pair of pulse conditioning circuits 56 and 58. Pulse conditioning circuit 56 comprises a one-shot circuit that squares up the rising and falling edges of the pulses received on lead 54 and increases their length from approximately 100 nanoseconds to 300 nanoseconds. The pulse conditioning circuit 58 generates a pulse 61 having a duration of approximately 40 microseconds that begins upon receipt of the first pulse 48a; pulse 61 is conveyed on a lead 62.

The pulses placed on a lead 60 by the pulse conditioning circuit 56 are applied to the "clock input" pin of an 8-bit shift register 64. The "data-in" pin of shift register 64 is tied to a logic high voltage so that upon receipt of each pulse on lead 60, a logic 1 bit is shifted one place through the register. Connected to the output of shift register 64 are three sample and hold circuits 70, 72, and 74. A lead 64a couples the sample and hold circuit 70 to the zeroth bit position of shift register 64. A lead 64b couples the sample and hold circuit 72 to the first bit position of the shift register 64, and a lead 64c couples the sample and hold circuit 74 to the second bit position of shift register 64. Sample and hold circuits 70, 72, and 74 track a linearly varying voltage signal supplied on a lead 68 by a voltage ramp generator 66. The voltage ramp generator 66 begins producing the linearly varying voltage signal upon receipt of the leading edge of the pulse 61 on a ramp enable lead 63. As the logic 1's are shifted through shift register 64 with the receipt of each of the pulses 48a, 48b, and 48c from the transmitter, each of the sample and hold circuits 70, 72, and 74 samples the linearly varying voltage signal on lead 68. The sample and hold circuit 70 samples a voltage V'_1, while the sample and hold circuits 72 and 74 sample voltages V'_2 and V'_3, respectively. A math processor block 76 receives the sampled voltages from the sample and hold

circuits 70, 72, and 74 on leads 71, 73, and 75, respectively. Math processor block 76 scales the sampled voltages according to the following equation:

$$\text{Sensor value} = ((V'_2 - V'_1) - 0.1(V'_3 - V'_1))/\ 0.8(V'_3 - V'_1) \qquad \text{Eq. 1}$$

Equation 1 scales the voltages sampled by sample and hold circuits 70, 72, and 74 between 0-100% such that if V'_2 is 10% of V'_3-V'_1, the sensor value equals 0%, or if V'_2 is 90% of V'_3-V'_1, the sensor value equals 100%. Equation 1 serves to "undo" the offset created by the initial calibration of V_1 and V_3, as described above. This offset calibration is added so that a sensor output signal of 0% or 100% can be transmitted without requiring the second pulse to overlap either the first and third pulses. If Equation 1 is applied to the pulses shown in FIGURE 3, a value of 60% is obtained, which is equal to the normalized output signal of the sensor. The circuits that comprise math block 76 are more fully described below.

An analog-digital (A/D) converter 82 receives an output signal from math processor block 76 on a lead 78 and a reference signal on a lead 79. A/D converter 82 converts the ratio of the signal on lead 78 to the signal on lead 79 from an analog signal to a 12-bit digital word that is transmitted to a line driver 86 over a lead 84. Line driver 86 transmits the digital word on a data bus 92 to a microprocessor (not shown). An out of range circuit 94 also receives an "out of range (low)" signal from math processor block 76 on a lead 80 and an "out of range (high)" signal on a lead 81. In a preferred embodiment, if a signal on lead 80 or 81 indicates that the output value of sensor 20 is less than 0% or greater than 100% of the expected output signal range of the sensor 20, the out of range circuit 94 sends a one-bit signal on a lead 96 that indicates the output signal of sensor 20 is out of range. A data valid circuit 88 is coupled to third bit position of shift register 64 by a lead 64d. The data valid circuit 88 determines if more than three clock pulses are received by shift register 64 in a predefined time interval, and produces a logic 1 output on a lead 90 when the shift register receives a fourth clock input on lead 60. The data valid circuit 88 is also coupled to the "enable" pin of line driver 86, so that if the data is invalid, the line driver circuit is not enabled and the erroneous 12-bit word is not transmitted on data bus 92.

FIGURE 5 shows a schematic diagram of the math block 76 illustrated in FIGURE 4. Math block 76 receives a signal V'_1 on lead 71, a signal V'_2 on lead 73 and a signal V'_3 on lead 75. A summation block 100 subtracts the signal

on lead 71 from the signal on lead 73. Similarly, a summation block 104 subtracts the signal on lead 71 from the signal on lead 75. The output of summation block 100 is coupled to a summation block 114 by a lead 102. The output of summation block 104 is coupled to a resistor divider network by a lead 106. The resistor divider network comprises six resistors R_1, R_2, R_3, R_4, R_5, and R_6. The resistance ratio of resistors R_1 to R_2 is such that the voltage on a lead 112 is equal to .8 $(V'_3 - V'_1)$. The resistance ratio of resistor R_3 to resistor R_4 is such that the voltage on a lead 110 is equivalent to 0.9 $(V'_3 - V'_1)$. Finally, the resistance ratio of resistor R_5 to resistor R_6 is such that the voltage on a lead 108 is equal to 0.1 $(V'_3 - V'_1)$.

Summation block 114 subtracts the signal on lead 108 from the signal on lead 102. The output of summation block 114 $(V'_2 - V'_1) - 0.1\ (V'_3 - V'_1)$ is placed on lead 78, which is coupled to the input of the A/D converter 82 (shown in FIGURE 4). Two comparator circuits 116 and 118 determine if the output signal of the sensor is within an acceptable range. Coupled to an inverting input of comparator 116 is the signal on lead 102. Coupled to the noninverting input of comparator 116 is the signal on lead 108. If the value of 0.1 $(V'_3 - V'_1)$ exceeds the value of $(V'_2 - V'_1)$ then comparator 116 places an "out of range (low)" signal on lead 80. Similarly, comparator 118 determines if the output signal of sensor 20 exceeds the acceptable range. Coupled to the inverting input of comparator 118 is the signal on lead 110 and coupled to the noninverting input of comparator 118 is the signal on lead 102. If the value $(V'_2 - V'_1)$ exceeds the value of 0.9 $(V'_3 - V'_1)$, then comparator 118 places an "out of range (high)" signal on lead 81. If the signal on either lead 80 or 81 goes high, out of range circuit 94 sends a 1 bit signal on lead 96 that indicates the output value of sensor 20 is out of range. The signal on lead 79, 0.8 $(V'_3 - V'_1)$, is coupled to the reference input of A/D converter 82 (shown in FIGURE 4) so that the output value of A/D converter 86 is proportional to the ratio set forth in Equation 1.

While the preferred embodiment of the invention has been illustrated and described with respect to sensors used in the aircraft industry, the present invention is not limited to use in an aircraft control system. This method and apparatus can be used in any control system where it is necessary to transmit information from a remotely located sensor to a central computer.

Furthermore, although the present invention has been illustrated with respect to the preferred embodiment, it will be appreciated that various changes can be made without departing from the spirit and scope of the invention. For

example, as an alternative to the receiver circuit shown in FIGURE 3, a microprocessor having internal timing circuits can process the times at which the three pulses transmitted from LED driver 46 on fiber optic cable 47 are received. The microprocessor can easily be programmed to compare the time between first pulse 48a and the second pulse 48b with the time between the first pulse 48a and the third pulse 48c and thereby ratiometrically determine the value of the output signal of the sensor. Additionally, those skilled in the art will realize that more than one pulse could be transmitted in order to convey the value of the output signal from more than one sensor according to the method described above. Therefore, it is intended that the scope of the present invention be determined only by reference to the following claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A method of transmitting information indicative of an output signal of a sensor to a remote location, the method comprising the steps of:

determining times for transmitting each of a first signal, a second signal, and a third signal to the remote location, wherein the time at which the second signal is to be transmitted and the times at which the first and third signals are transmitted are ratiometrically related to the value of the output signal of the sensor; and

transmitting the first signal, the second signal, and the third signal to the remote location at the times thus determined.

2. The method of Claim 1,wherein the step of transmitting the first, second and third signals comprises the steps of:

transmitting a first pulse at a time t_1;

transmitting a second pulse at a time t_2;

transmitting a third pulse at a time t_3,; and

wherein a ratio of a time interval $(t_2 - t_1)$ to a time interval $(t_3 - t_1)$ is indicative of the output signal of the sensor.

3. The method of Claim 2, further comprising the steps of:

generating a reference signal that varies between a first predefined limit and a second predefined limit;

comparing the reference signal to the first predefined limit, to the output signal of the sensor, and to the second predefined limit; and

wherein the step of transmitting the first pulse is done when the reference signal is substantially equal to the first predefined limit, the step of transmitting the second pulse is done when the reference signal is substantially equal to the output signal of the sensor, and the step of transmitting the third pulse is done when the reference signal is substantially equal to the second predefined limit.

4. The method as in Claim 3, wherein the step of generating a reference signal comprises the step of;

producing a varying signal having a magnitude that varies in a predefined manner between the first and the second predefined limits.

5. The method of Claim 3, wherein the first predefined limits is substantially less than a minimum sensor value by a predefined fraction of a difference between the first and second predefined limits.

6. The method of Claim 3, wherein the second predefined limit is substantially greater than a maximum sensor output value by a predefined fraction of a difference between the first and second predefined limits.

7. A method for transmitting information indicative of an output signal of a sensor to a remotely located receiver, the method comprising:

transmitting a first pulse to the remote receiver at a time t_1;

transmitting a second pulse to the remote receiver at a time t_2; and

transmitting a third pulse to the remote receiver at a time t_3;

wherein the ratio of the time intervals $(t_2-t_1)/(t_3-t_1)$ is proportional to the output signal of the sensor.

8. The method according to Claim 7, further comprising the steps of:

generating a linearly varying reference signal that varies between a first predefined limit and a second predefined limit;

sampling the output signal of the sensor; and

comparing the reference signal to the first predefined limit, to the output signal of the sensor, and to the second predefined limit;

wherein the first pulse is transmitted when the reference signal is substantially equal to the first predefined limit, the second pulse is transmitted when the reference signal is substantially equal to the output signal of the sensor, and the third pulse is transmitted when the reference signal is substantially equal to the second predefined limit.

9. Apparatus for transmitting an output signal of a sensor to a remote receiver circuit, wherein a magnitude of the output signal lies between a minimum value and a maximum value, comprising:

means for determining a first time, a second time, and a third time at which corresponding first, second, and third signals are transmitted to the remote receiver;

means for transmitting the first signal, the second signal, and the third signal to the remote receiver, wherein the times at which the first and third signals are transmitted are predefined, and the time at which the second signal is transmitted is a function of the value of the output signal of the sensor.

10. The apparatus as in Claim 9, wherein the means for transmitting the first, second, and third signals comprises:

means for transmitting a first pulse at a time t_1, a second pulse at a time t_2, and a third pulse at a time t_3;

wherein the means for determining the times for transmitting the first, second, and third pulses selects those times so that a ratio of a time interval $(t_2 - t_1)$ to a time interval $(t_3 - t_1)$ is indicative of the magnitude of the output signal of the sensor.

11. The apparatus as in Claim 9, further comprising:

a signal generating circuit for producing a reference signal that varies between a first predefined limit and a second predefined limit in a predefined manner; and

a comparator circuit for comparing the reference signal to a first predefined limit, to the output signal of the sensor, and to a second predefined limit, wherein the comparator circuit is coupled to the means for transmitting such that the means for transmitting transmits the first signal when the reference signal is substantially equal to the first predefined limit, transmits the second signal when the reference signal is substantially equal to the output signal of the sensor, and transmits the third signal when the reference signal is substantially equal to the second predefined limit.

12. The apparatus as in Claim 9, further comprising:

a fiber optic cable that extends between the sensor and the remote receiver circuit, wherein the first, second, and third signals are transmitted on the fiber optic cable.

13. The apparatus as in Claim 11, wherein the first predefined limit is substantially less than minimum sensor value by a predefined fraction of a difference between the first and second predefined limits.

14. The apparatus as in Claim 11, wherein the second predefined limit is substantially greater than a maximum sensor value by a predefined fraction of a difference between the first and second predefined limits.

15. The apparatus as in Claim 10, wherein the remote receiver circuit comprises:

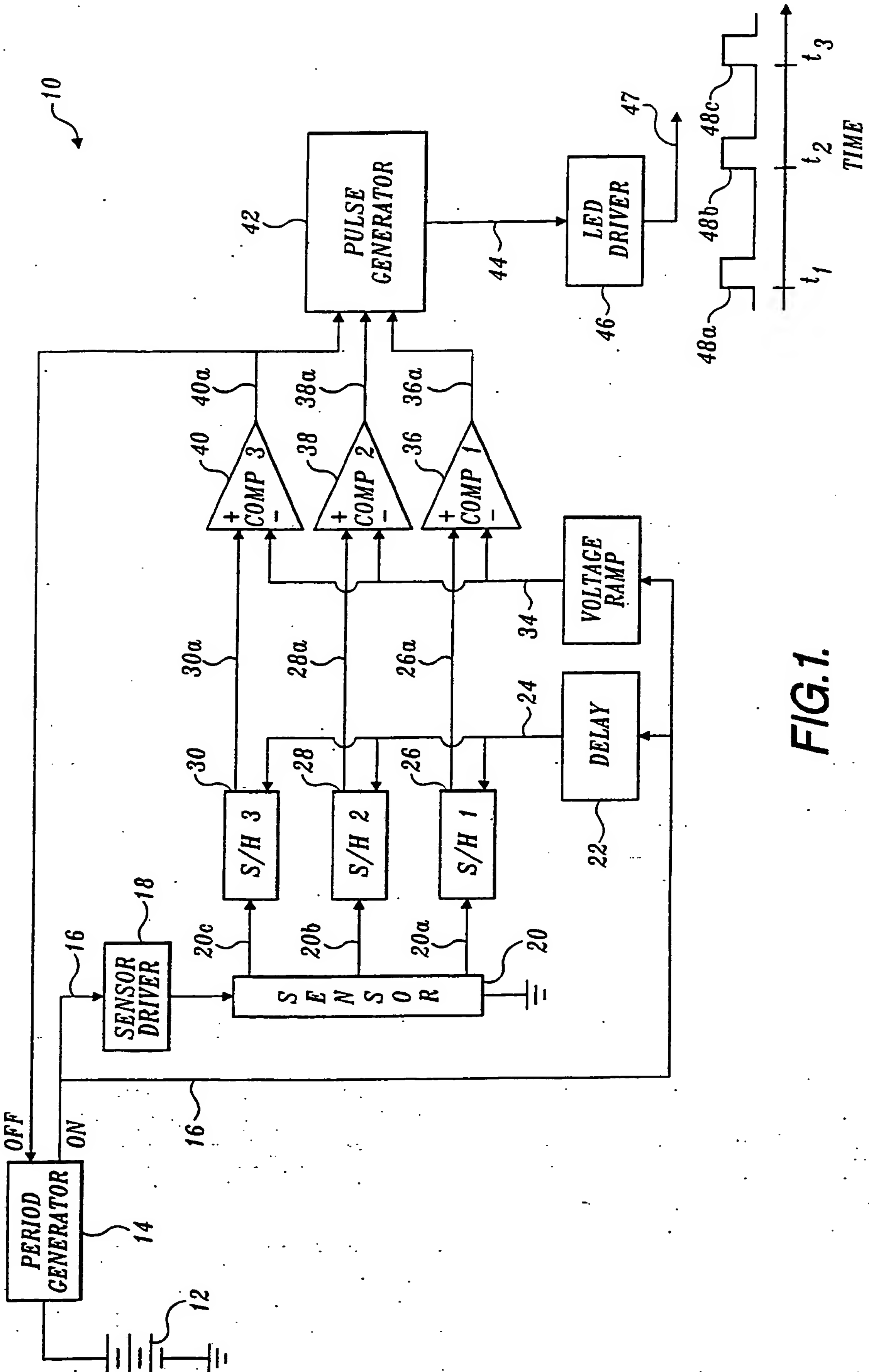
means for receiving the first, second, and third pulses; and

means for computing a ratio of a time interval between times at which the first and the second pulse are received to an interval between times at which the first and third pulses are received.

16. The apparatus as in Claim 15, wherein the means for computing the ratio comprises:

means for producing a second varying reference signal that varies in the predefined manner upon the receipt of the first pulse;

means for obtaining a first sample of the second varying reference signal at a time substantially coincident with the receipt of the first pulse, a second sample of the second varying reference signal at a time substantially coincident with the receipt of the second pulse and a third sample of the second varying reference signal at a time substantially coincident with the receipt of the third pulse, wherein a magnitude of a difference between the first sample and the second sample and a magnitude of a difference between the first and third samples is ratiometrically related to the output signal of the sensor.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PERIOD GENERATOR
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SENSOR DRIVER
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SENSOR
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48a
48b
48c
t_1
t_2
t_3
TIME

FIG.1.

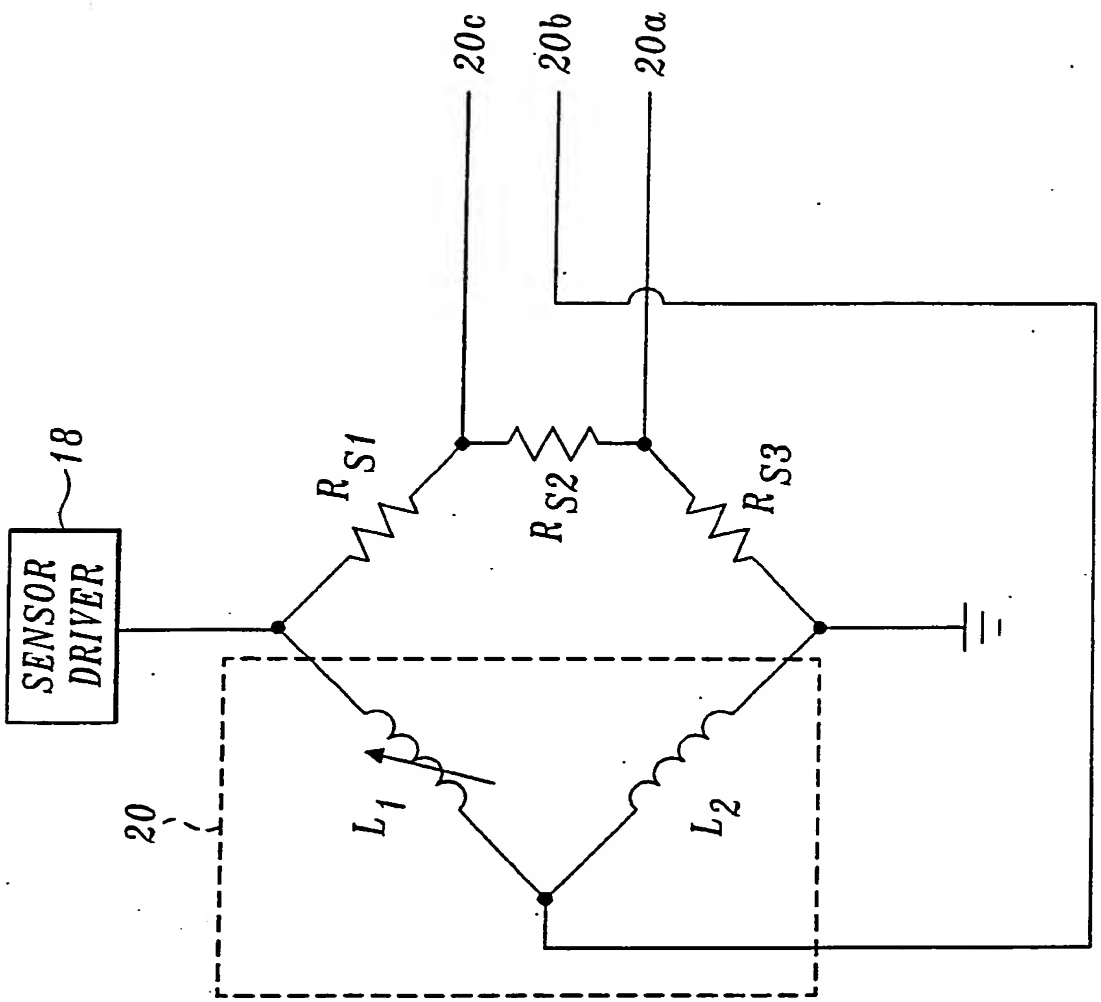


FIG.2.

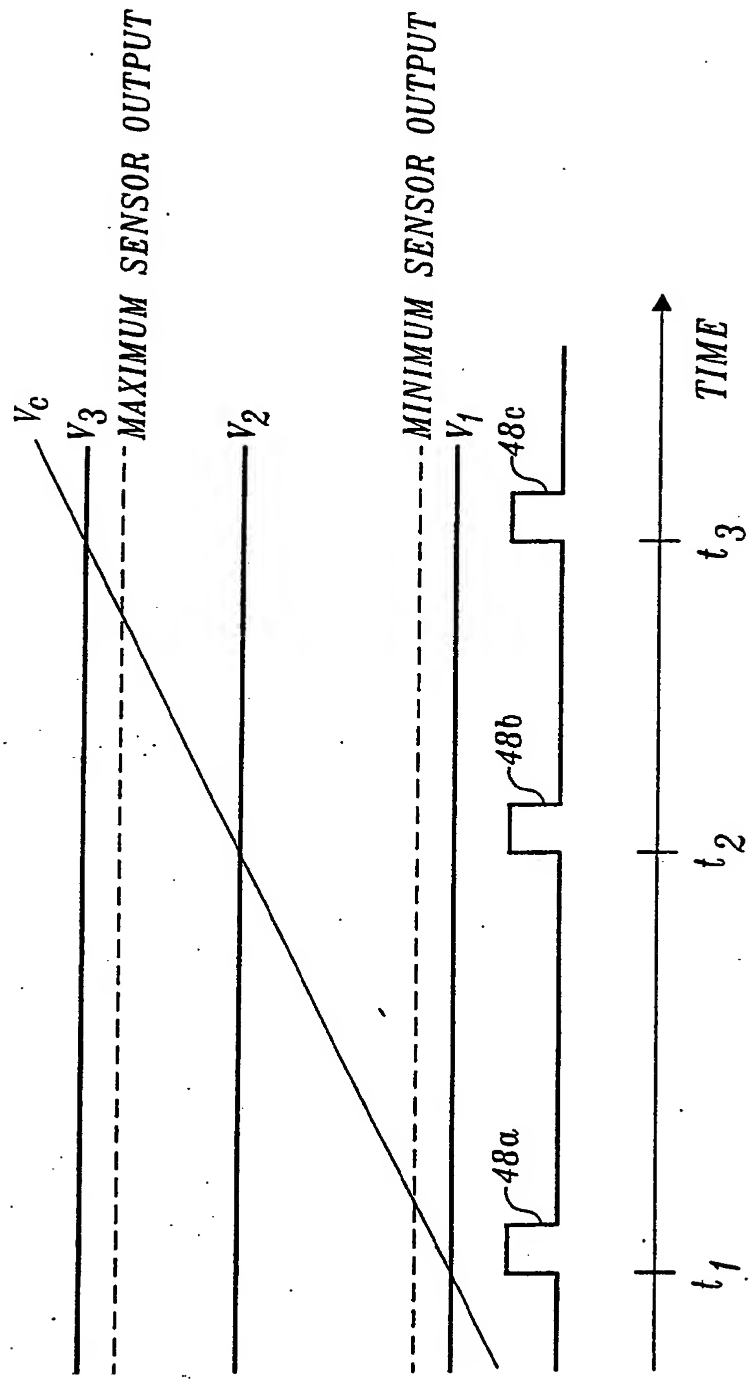
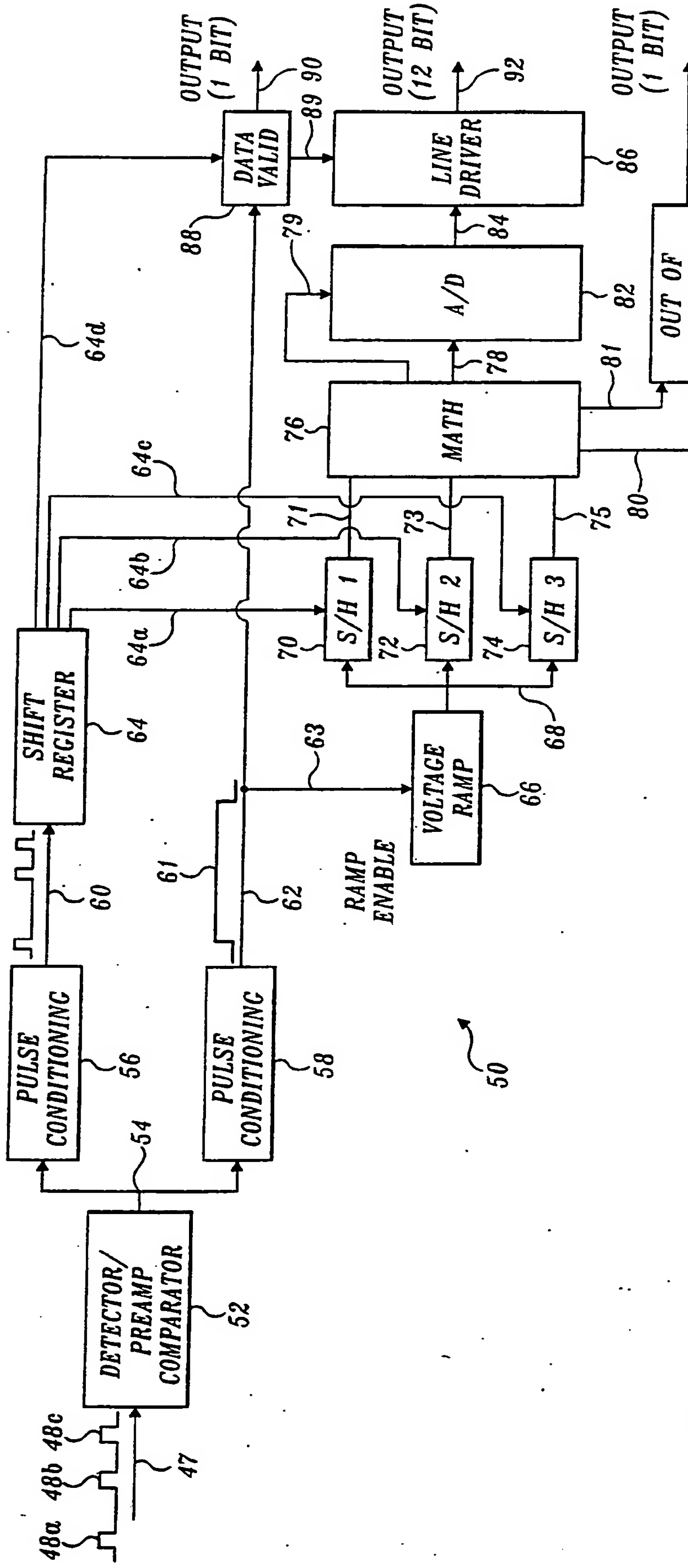

MAXIMUM SENSOR OUTPUT
MINIMUM SENSOR OUTPUT
V_c
V_3
V_2
V_1
48a
48b
48c
t_1
t_2
t_3
TIME

FIG.3.



48a
48b
48c
47
DETECTOR/ PREAMP COMPARATOR
52
54
PULSE CONDITIONING
56
PULSE CONDITIONING
58
60
61
62
SHIFT REGISTER
64
64a
64b
64c
64d
63
RAMP ENABLE
VOLTAGE RAMP
66
68
S/H 1
S/H 2
S/H 3
70
72
74
71
73
75
MATH
76
78
79
80
81
A/D
82
84
OUT OF RANGE
94
DATA VALID
88
89
90
LINE DRIVER
86
92
96
OUTPUT (1 BIT)
OUTPUT (12 BIT)
OUTPUT (1 BIT)
50

FIG.4.

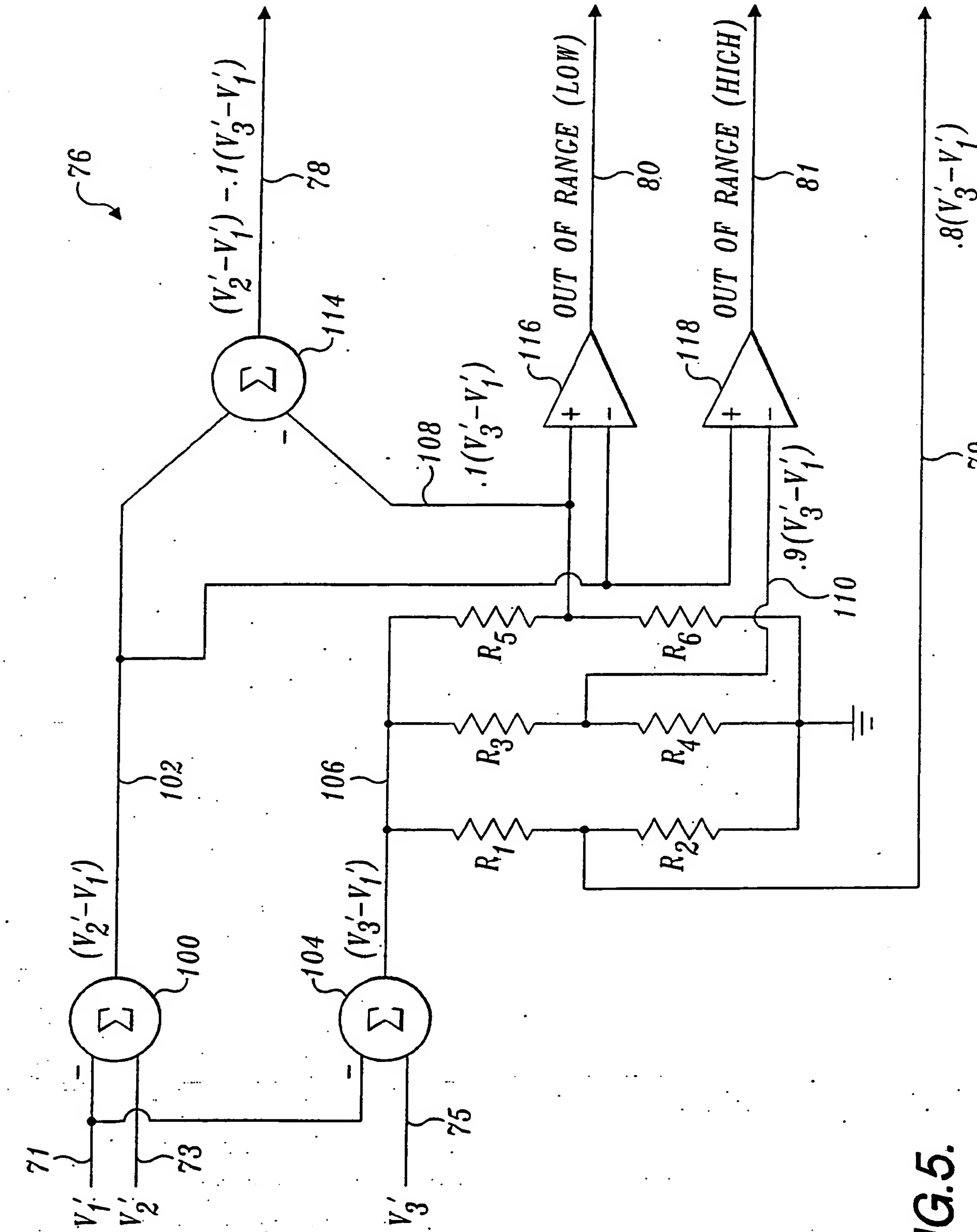

76
$(V_2'-V_1')-.1(V_3'-V_1')$
78
OUT OF RANGE (LOW)
80
OUT OF RANGE (HIGH)
81
$.8(V_3'-V_1')$
114
116
118
$.1(V_3'-V_1')$
108
$.9(V_3'-V_1')$
110
79
R_5
R_6
R_3
R_4
R_1
R_2
102
106
$(V_2'-V_1')$
$(V_3'-V_1')$
100
104
71
73
75
V_1'
V_2'
V_3'

FIG.5.

INTERNATIONAL SEARCH REPORT

International Application No PCT/US 92/06254

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all)[6]

According to International Patent Classification (IPC) or to both National Classification and IPC

Int.Cl. 5 G08C19/24

II. FIELDS SEARCHED

Minimum Documentation Searched[7]

Classification System	Classification Symbols
Int.Cl. 5	G08C

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched[8]

III. DOCUMENTS CONSIDERED TO BE RELEVANT[9]

Category °	Citation of Document, [11] with indication, where appropriate, of the relevant passages [12]	Relevant to Claim No.[13]
X	EP,A,0 162 990 (ELECTRICITE DE FRANCE) 4 December 1985 see page 3, line 22 - page 6, line 18; figures 1-6	1-4, 7-12,15, 16
X	WO,A,8 905 738 (COMPAGNIE GENERALE DES ETABLISSEMENTS MICHELIN - MICHELIN & CIE) 29 June 1989 see the whole document	1,2,7,9, 10

° Special categories of cited documents : [10]

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"&" document member of the same patent family

IV. CERTIFICATION

Date of the Actual Completion of the International Search	Date of Mailing of this International Search Report
02 OCTOBER 1992	15. 10. 92
International Searching Authority	**Signature of Authorized Officer**
EUROPEAN PATENT OFFICE	WANZEELE R.J.

ANNEX TO THE INTERNATIONAL SEARCH REPORT ON INTERNATIONAL PATENT APPLICATION NO. US 9206254 SA 63002

This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on 02/10/92
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Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP-A-0162990	04-12-85	FR-A-	2552874	05-04-85
		CA-A-	1248200	03-01-89
		DE-A-	3472161	21-07-88
		JP-A-	60095699	29-05-85
		US-A-	4651151	17-03-87
WO-A-8905738	29-06-89	FR-A-	2624802	23-06-89
		AU-A-	2819389	19-07-89
		DE-A-	3868941	09-04-92
		EP-A,B	0390843	10-10-90
		JP-T-	3501713	18-04-91
		US-A-	5054315	08-10-91

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